

## MODULE-5

### Nanomaterials

#### NANOTECHNOLOGY

**Introduction:** *Nanotechnology* originates from the *Greek word meaning “dwarf”*. A *nanometer is one billionth ( $10^{-9}$ ) of a meter*, which is tiny, only the length of ten hydrogen atoms, or about one hundred thousandth of the width of a hair, Although scientists have manipulated matter at the nanoscale for centuries, calling it physics or chemistry, it was not until a new generation of microscopes was invented in the nineteen eighties in IBM, Switzerland that the world of atoms and molecules could be visualized and managed.

**Definition:** *Nanotechnology can be defined as the manipulation of atoms and molecules (one billionth) scale (1-100 nm) to produce devices, structures or systems having at least one novel or superior property. Materials having at least one dimension in the nanoscale are called **nanomaterials**. Conceptualization of nanotechnology was done by **Richard Feynman in 1959**. The impact of nanotechnology is quite significant. When the bulk materials are reduced to nanometer size, the properties exhibited by these nonmaterial's are of tremendous use. For example,*

1. Opaque materials become transparent (copper),
2. Insoluble substances become soluble (gold),
3. Stable materials become combustible (aluminium).

*In fact, at normal scales, gold is chemically inert but at nanoscales, gold nanoparticles can serve as potent chemical catalysts. The study of these nanomaterials is known as **nanoscience**.*

**Properties of nanomaterials:** *Physical and chemical properties of nonmaterial's are significantly different from those of single atoms/molecules and bulk material of the same chemical composition.*

**Difference in properties is related to,**

1. The spatial arrangement of molecules/structure,
2. Electronic structure,
3. Energetic,
4. Chemical reactivity
5. Phase change or catalytic activity.

*Properties remain same at first (size being reduced from macro to micro), and slowly small changes begin to take place as the particle size is reduced further from micro to the nanoscale range (generally observed below, 100 nm).*

### **Size dependent properties**

1). **Surface area:** If a macroscopic object is divided into smaller parts, the ratio of surface atoms to interior atoms becomes a significant number of total fractions of atoms. *The inverse relation between the particle size and surface area is responsible for the remarkable changes in the physical properties of nonmaterial's.*

Properties like catalytic activity, gas adsorption; chemical reaction depends on surface area.  
Ex: Gold is catalytically inactive in bulk but nano gold is highly catalytically active.

2). **Electrical properties:** Electronic bands in bulk material are continuous due to the overlap of billions of atoms, but in nano-size material very few molecules are present so electrical band separates. Hence some metals which are good conductors in bulk become semiconductor and insulator at the nano level.

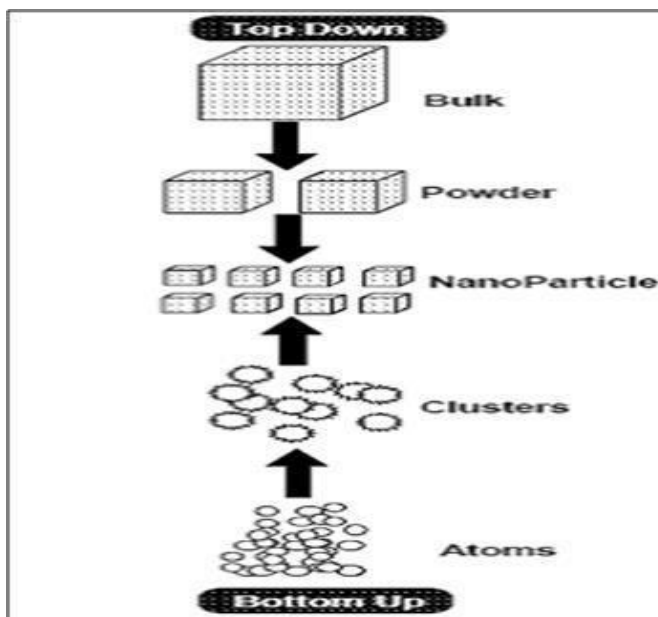
3). **Optical Properties:** Nanomaterials exhibit different colors from bulk materials. The discrete electronic state of nanomaterial allows absorption and emission of light of specified.

4). **Thermal properties:** The large increase in surface energy and the change in interatomic spacing as a function of nanoparticle size mentioned above have a marked effect on material properties. For instance, the melting point of gold particles, which is really a bulk thermodynamic characteristic, has been observed to decrease rapidly for particle sizes less than 10 nm. Smaller particles have higher melting points.

5). **Catalytic properties:** Nanomaterial-based catalysts are usually heterogeneous catalysts broken up into metal nanoparticles in order to speed up the catalytic process. Metal nanoparticles have a higher surface area so there is increased catalytic activity because more catalytic reactions can occur at the same time. Nanoparticle catalysts can also be easily separated and recycled with more retention of catalytic activity than their bulk counterparts.

### **General methods of Synthesis:**

There are two approaches for the synthesis of nanomaterials and the fabrication of nanostructures. Top down approach refers to slicing or successive cutting off a bulk material to get nano-sized particle. Bottom-up approach refers to the build-up of a material from the bottom: atom by atom, molecule by molecule or cluster by cluster. Both approaches play very important role in modern industry and most likely in nanotechnology as well. There are advantages and disadvantages to both approaches.



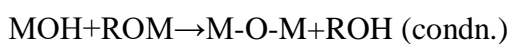
Sol-gel process:

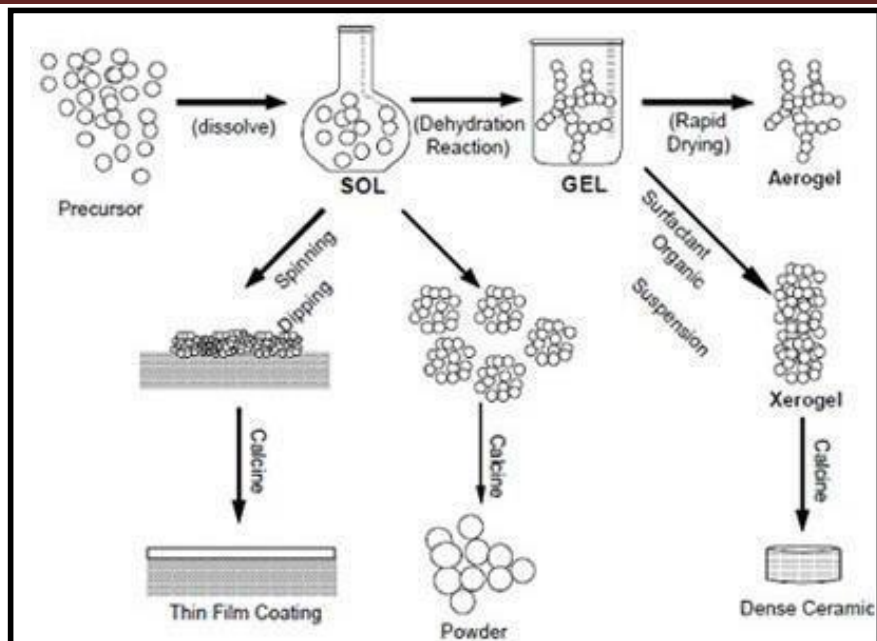
The sol-gel method of synthesizing nanomaterial is very popular amongst chemists and is widely employed to prepare oxide materials.

The sol-gel process can be characterized by a series of distinct steps.

**Step 1:** Formation of different stable solutions of the alkoxide or solvated metal precursor (**the sol**).

**Step 2: Gelation** resulting from the formation of an oxide- or alcohol- bridged network (the gel) by a polycondensation or polyesterification reaction that results in a dramatic increase in the viscosity of the solution.





**Step 3: Aging of the gel (Syneresis)**, during which the polycondensation reactions continue until the gel transforms into a solid mass, accompanied by contraction of the gel network and expulsion of solvent from gel pores. The aging process of gels can exceed 7 days and is critical to the prevention of cracks in gels that have been cast.

**Step 4: Drying of the gel**, when water and other volatile liquids are removed from the gel network. This process is complicated due to fundamental changes in the structure of the gel. The drying process has itself been broken into four distinct steps: (i) the constant rate period, (ii) the critical point, (iii) the falling rate period, (iv) the second falling rate period.

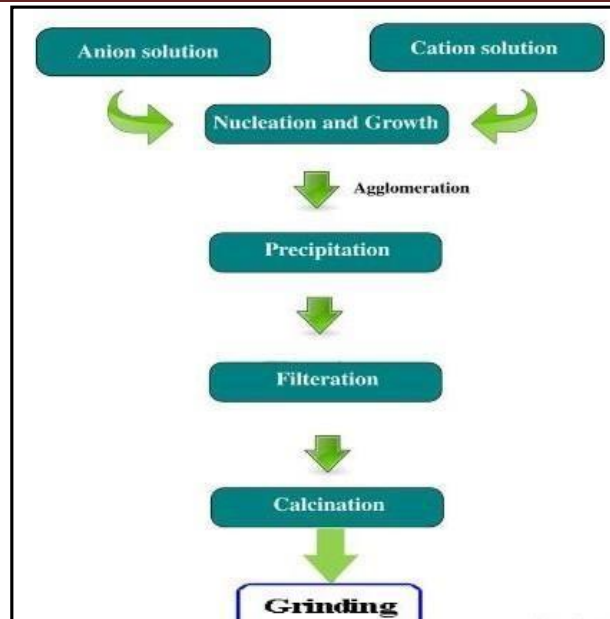
If isolated by thermal evaporation, the resulting monolith is termed a *xerogel*. If the solvent (such as water) is extracted under supercritical or near supercritical conditions, the product is an *aerogel*.

**Step 5: Dehydration**, during which surface-bound M-OH groups are removed, thereby stabilizing the gel against rehydration. This is normally achieved by calcining the monolith at temperatures up to 800°C.

**Step 6: Densification and decomposition** of the gels at high temperatures ( $T > 800^\circ\text{C}$ ). The pores of the gel network are collapsed, and remaining organic species are volatilized. The typical steps that are involved in sol-gel processing are shown in the schematic diagram below.

### Precipitation method

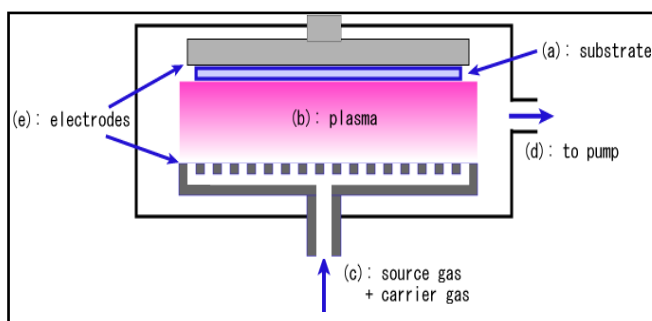
- In this technique, an inorganic metal such as acetate, chloride, nitrate is dissolved in aqueous medium.
- Metal cations exist in the form of metal hydrate species such as  $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$  and  $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ .
- When a precipitating agent such as NaOH or  $\text{NH}_4\text{OH}$  is added, these species get hydrolysed with the increase in pH, condensation of hydrolysed species takes place. These concentration of the solution is termed as supersaturation. At this concentration only, formation of nucleation initiates. The particles get precipitated into metal hydroxide.
- The above precipitate is filtered, washed with water and calcined at higher temperature to remove the counter anions of the metal salt used such as acetate or nitrate then finally grinding to get a fine powder.



### Chemical Vapour Condensation (CVC) method

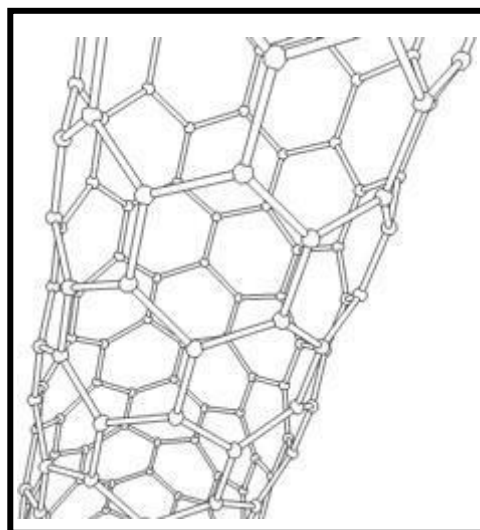
**Chemical vapor deposition (CVD)** is a chemical process used to produce high quality, high-performance, solid materials. The process is often used in the semiconductor industry to produce thin films. In typical CVD, the wafer (substrate) is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit. Frequently, volatile by-products are also produced, which are removed by gas flow through the reaction chamber.

Microfabrication processes widely use CVD to deposit materials in various forms, including: monocrystalline, polycrystalline, amorphous, and epitaxial. These materials include: silicon, carbon fiber, carbon nanofibers, fluorocarbons, filaments, carbon nanotubes, SiO<sub>2</sub>, silicon-germanium, tungsten, silicon carbide, silicon nitride, silicon oxynitride, titanium nitride, and various high-k dielectrics. CVD is also used to produce synthetic diamonds.



### Carbon Nanotubes

1. In 1991, during the optimization of the fullerene-synthesis by arc discharges, small tubes were found (by Sumio Iijima, characterized by transmission electron microscopy TEM).
2. Nanotubes are members of the fullerene structural family ( a name derived from their long, hollow structure with the walls formed by one-atom-thick sheets of carbon, called graphene).
3. These sheets are rolled at specific and discrete ("chiral") angles, and the combination of the rolling angle and radius decides the nanotube properties.
4. Individual nanotubes naturally align themselves into "ropes" held together by van der Waals forces, more specifically, pi-stacking.
5. Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs) and Double-wall Nanotubes (DWNT).
6. The chemical bonding of nanotubes is composed entirely of  $sp^2$  bonds, similar to those of graphite. These bonds, which are stronger than the  $sp^3$  bonds found in alkanes and diamond, provide nanotubes with their unique strength.



#### **Preparation :**

Nanocyl uses the "Catalytic Carbon Vapor Deposition" method for producing Carbon Nanotube Technologies. This proven industrial process is well known for its reliability

and scalability. It involves growing nanotubes on substrates, thus enabling uniform, large-scale production of the highest-quality carbon nanotubes worldwide.



### Properties:

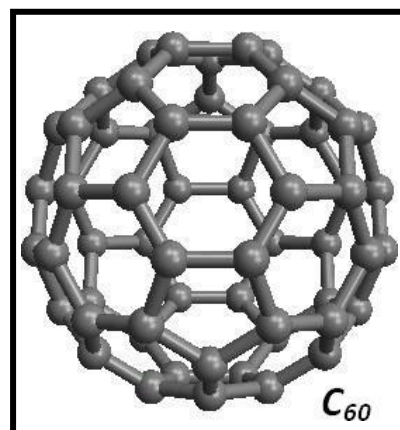
1. Carbon nanotubes are the strongest and stiffest materials yet discovered in terms of tensile strength (~100 GPa) and elastic modulus respectively (due to covalent  $sp^2$  bonds).
2. Standard single-walled carbon nanotubes can withstand a pressure up to 25 GPa without deformation.
3. Maximum electrical conductance of a single-walled carbon nanotube is  $2G_0$ .
4. All nanotubes are expected to be very good thermal conductors along the tube, exhibiting a property known as "ballistic conduction".

**Applications:** Conductive plastics, Structural composite materials, Flat-panel displays, Gas storage Antifouling paint, Micro- and nano-electronics, Radar-absorbing coating, Technical textiles, Ultra-capacitors, Atomic Force Microscope (AFM) tips, Batteries with improved lifetime, Biosensors for harmful gases, Extra strong fibers.

### Fullerenes

Fullerene a new allotrope of carbon, in which the atoms are arranged in closed shells, having the structure of a truncated icosahedron (a polyhedron). (Nobel Prize, 1996 for Kroto, Curl and Smalley). Named as Buckminsterfullerene (after Buckminster Fuller who designed geodesic domes in the 1960's).

1. First time produced isolable quantities of  $C_{60}$  by causing an arc between two graphite rods to burn in a helium atmosphere (extracting the carbon condensate so formed using an organic solvent).
2. Other carbon clusters such as  $C_{70}$ ,  $C_{76}$ ,  $C_{78}$  and  $C_{84}$  are also studied, with new and unexpected properties, which lead to a new branch of chemistry developed, with consequences in such diverse areas as astrochemistry, superconductivity and materials chemistry/physics.
3. Fullerenes consist of 20 hexagonal and 12 pentagonal rings as the basis of an icosahedral symmetry closed cage structure, with each carbon atom is bonded to three others and is  $sp^2$  hybridised.
4.  $C_{60}$  molecule has two bond lengths - the 6:6 ring bonds can be considered "double bonds" and are shorter than the 6:5 bonds.  $C_{60}$  is not "super aromatic" as it tends to avoid double bonds in the pentagonal rings, resulting in poor electron delocalisation and hence  $C_{60}$  behaves like an electron deficient alkene, and reacts readily with electron rich species.
5. The most striking property of the  $C_{60}$  molecule is its high symmetry. There are 120 symmetry operations (*most symmetric molecule*), like rotations around an axis or reflections in a plane, which map the molecule onto itself.

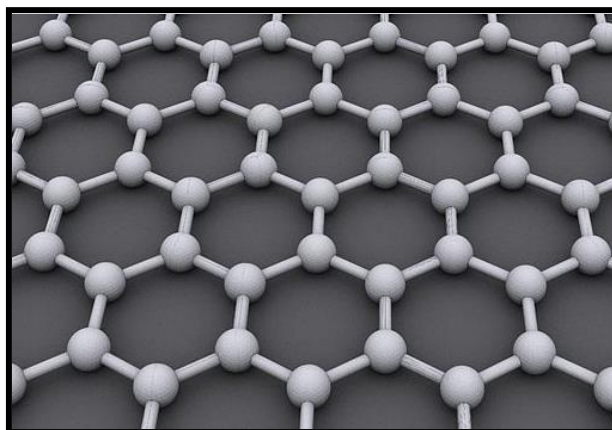


### Applications

Fullerenes have been extensively used for several biomedical applications including the design of high-performance MRI contrast agents, X-ray imaging contrast agents, photodynamic therapy and drug and gene delivery.

Graphenes

Graphene is a semi-metal with small overlap between the valence and the conduction bands (zero bandgap material). It is an allotrope (form) of carbon consisting of a single layer of carbon atoms arranged in a hexagonal lattice. It is the basic structural element of many other allotropes of carbon, such as graphite, diamond, charcoal, carbon nanotubes and fullerenes.



Graphene is a crystalline allotrope of carbon with 2-dimensional properties. Its carbon atoms are densely packed in a regular atomic-scale chicken wire (hexagonal) pattern.

Each atom has four bonds: one  $\sigma$  bond with each of its three neighbors and one  $\pi$ -bond that is oriented out of plane. The atoms are about 1.42 Å apart.

Graphene's hexagonal lattice can be regarded as two interleaving triangular lattices. This perspective was successfully used to calculate the band structure for a single graphite layer using a tight-binding approximation. Graphene's stability is due to its tightly packed carbon atoms and a  $sp^2$  orbital hybridization – a combination of orbitals  $s$ ,  $p_x$  and  $p_y$  that constitute the  $\sigma$ -bond. The final  $p_z$  electron makes up the  $\pi$ -bond. The  $\pi$ -bonds hybridize together to form the  $\pi$ -band and  $\pi^*$ -bands. These bands are responsible for most of graphene's notable electronic properties, via the half-filled band that permits free-moving electrons.

**Applications**

- Graphene is a transparent and flexible conductor that holds promise for various material/device applications, including solar cells, light-emitting diodes (LED), touch panels and smart windows or phones.
- Graphene has also been used in other fundamental electronic devices, such as capacitors and Field Effect Transistors (FETs).

\*\*\*\*\* END\*\*\*\*\*

# POLYMERS

## Introduction

Polymers are the high molecular weight compounds obtained by repeated union of simple molecules (Monomers). Ex: Starch, silk, wool, Polyvinyl chloride, Polyethylene, Nylon 6,6 etc.

## Classification of polymers.

Polymers are classified into two types as follows:

i) *Natural polymers*: These are the polymers obtained naturally by plants and animals.

Ex: Silk, wool, natural rubber, protein, starch, cellulose, etc.

ii) *Synthetic Polymers*: These are artificially prepared polymers also known as manmade polymers. Ex: PVC, Nylon 6.6, Polyethylene, Phenolformaldehydesin etc.,

**Monomer**: These are the simple molecules, which combine with each other to form polymers. These are the building blocks of Polymer.

**Polymerization**: The process of linking of monomers to form polymers with or without the elimination of byproducts is called as polymerization.

**Degree of Polymerisation (n)**: The total number of monomers present in a single chain of polymer is called as degree of polymerization.

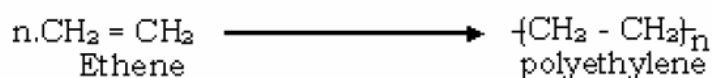
**Functionality**: The total number of bonding sites or functional groups present in a monomer is called functionality of the monomer

## Types of Polymerization

Polymerization reactions are classified into two types as follows.

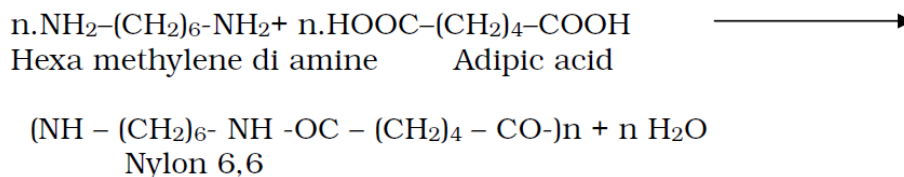
**1. Addition Polymerization**: In which, the monomers undergo rapid and self addition reactions to give a polymer without elimination of byproducts.

Ex: When large number of ethylene molecules undergoes addition polymerization, polyethylene polymer is obtained.



**2. Condensation Polymerization**: In which, the monomers having functional groups undergo repeated intermolecular condensation reactions to form a polymer with the elimination of simple molecules like water,

HCl, ammonia, phenol etc. Ex: When adipic acid and hexamethylene diamine undergoes condensation polymerization to form Nylon- 6,6 polymer.



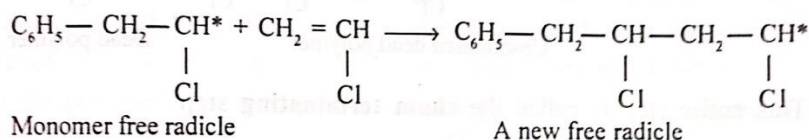
### Mechanism of addition Polymerization of Vinyl Chloride.

The free radical mechanism of addition polymerization of monomers takes place (proceeds) in three distinct stages, Initiation, Propagation & Termination

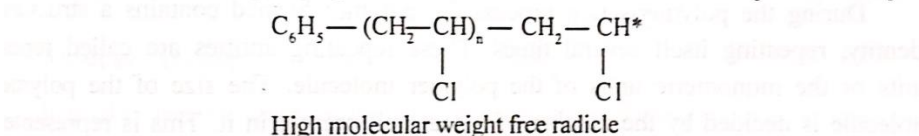
#### Mechanism

**1. Initiation:** Polymerisation is initiated by free radicals generated from initiators such as peroxides. An initiator on heating undergoes homolytic cleavage and generates free radical. The initiator free radical adds to vinyl monomer to produce a new free radical.

**2. Propagation:** The new free radical attacks another vinyl monomer to produce new free radical. The reactive monomer again reacts with another monomer and converts it into reactive monomer and growth of the polymer chain continues until termination occurs.

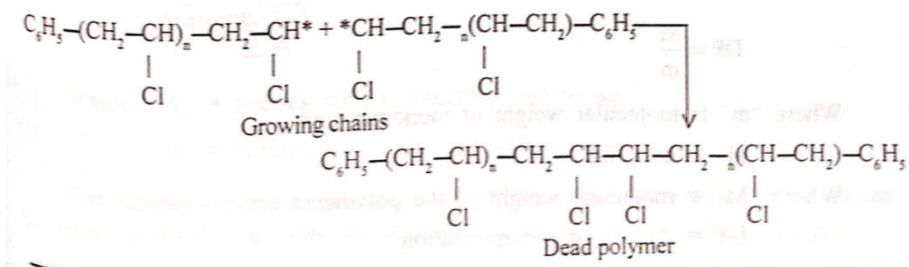


The structure of growing chain before termination can be represented by



**3. Termination:** Termination of growing polymer chain occurs by any one of the following reaction.

- i. Coupling of two growing polymer chains: When two growing polymer chains react with each other to form of a dead polymer chain.
- ii. Coupling of growing polymer chain with initiator free radical: When a growing polymer chain reacts with a initiator free radical to form a dead polymer chain.
- iii. Disproportionation: In this termination, a hydrogen atom from a growing chain is transferred to another growing chain, resulting in one of the dead polymer having unsaturated end.



### 1. Number Average Molecular weight [Mn]:

It is obtained by dividing the total weight of dispersed material with the

Where  $n_1, n_2, n_3$  are the number of molecules having masses  $M_1, M_2, M_3$  respectively. The above equation may also be written as;

$$\overline{Mn} = \frac{\sum n_i M_i}{\sum n_i}$$

Where  $M_i$  = masses simple monomer molecules

$n_i$  = number of monomer molecules.

The number average molecular weight  $\overline{Mn}$  assumes that each molecule makes an equal contribution to polymer properties regardless of the size or weight.

number of molecules present i.e

## 2) Weight Average Molecular Weight $[\overline{M}_w]$ :

It gives representation to various molecular species in proportion to their weight in the given material. Light scattering and sedimentation equilibrium techniques, which not only depends upon the number of particles in a given mass or volume but also on the molecular size give a weight average molecular weight of the macromolecules. Hence in the averaging process molecular weight of each individual species is multiplied by the weight and not by the number i.e.,

$$\overline{M}_w = \frac{m_1 M_1 + m_2 M_2 + m_3 M_3}{m_1 + m_2 + m_3}$$

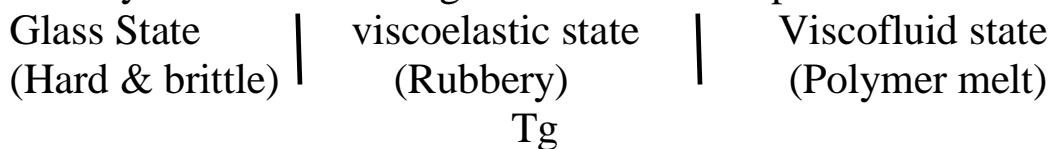
If  $n_1, n_2,$  denotes the number of molecules having masses  $M_1, M_2 \dots$  then  $m_1 = n_1 M_1, m_2 = n_2 M_2,$ . Hence the above equation may be written as

$$\overline{M}_w = \frac{n_1 M_1^2 + n_2 M_2^2 + n_3 M_3^2}{n_1 M_1 + n_2 M_2 + n_3 M_3}$$

$$\overline{M}_w = \frac{\sum n_i M_i^2}{\sum n_i M_i}$$

## Glass Transition Temperature

When an amorphous polymer is heated, it gets converted from hard brittle state (glassy state) to a soft flexible state (rubbery state). The temperature at which the polymer transforms from a hard and glassy state to soft and rubbery state is called as glass transition temperature.



## Factors affecting glass transition temperature

**1. Chain Flexibility:** Higher flexibility of a polymeric chain leads to lower T<sub>g</sub>. Linear polymer chains containing C-C, C-O or C-N single bonds have high degree of freedom of rotation i.e., more chain flexibility leads to lower T<sub>g</sub>. Presence of aromatic or cyclic groups on the back bone of carbon atoms hinder the freedom of rotation i.e., chain flexibility decreases and causes an increase in T<sub>g</sub>. Crystalline polymers are tougher, stiffer and more resistant to solvents.

**Ex:** T<sub>g</sub> of polyethylene is -110 °C (Linear) whereas Polystyrene is 100 °C (Presence of phenyl group).

**Cross-linking and branching:** A small amount of branching will tend to lower T<sub>g</sub> and a high density of branching reduces chain mobility and



elevates the Tg. The cross linking brings the polymer chain closer, lowers free volume and restricts molecular motion and hence rise in Tg. **Ex:** Tg of polyethylene is  $-110\text{ }^{\circ}\text{C}$  (no branches) whereas Polystyrene is  $100\text{ }^{\circ}\text{C}$  (Presence of phenyl side group).

**2. Intermolecular forces:** The presence of large number of polar groups in the polymeric chain leads to strong intermolecular cohesive forces like hydrogen and Vander walls forces of attraction which restrict the segmental motion. As a result Tg increases.

**Ex:** Tg of polypropylene is  $-18\text{ }^{\circ}\text{C}$  whereas Nylon 6,6 is  $57\text{ }^{\circ}\text{C}$  (Presence of polar polyamide group).

**3. Molecular mass:** Higher the molecular mass more is the restriction in the molecular freedom, hence increase in Tg. However, Tg is not significantly affected by molecular mass if the degree of polymerization is above 250 or molecular mass more than 20,000.

**4. Stereo regularity of the polymer:** A syndiotactic polymer has a higher Tg than atactic polymer, which in turn has higher Tg than its isotactic stereoisomer.

### **Significance of Tg :**

1. It is used as a measure for evaluating the flexibility of a polymer and the type of response the polymeric material would exhibit to
2. Tg is very useful in choosing the right processing temperature for fabrication (moulding, calendaring and extrusion )
3. Tg is very useful in determining the coefficient of thermal expansion, heat resistant, refractive index, electrical property etc.,

### **Relationship between structure and property of a polymer**

The properties of a polymer such as its tensile strength, elasticity, chemical resistivity etc depend on the structure aspects of polymers such as molecular weight, crystallinity, nature of polymer chains, stereoregularity, presence of polar groups and plasticizers etc.

**1. Tensile strength :** A polymer should have more tensile strength for a particular use and it depends on

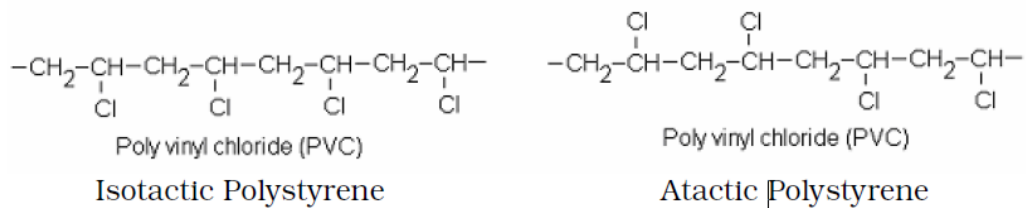
- a. Molecular weight of the polymer: Low molecular weight polymers are soft, gummy & less resistant to heat. But high molecular weights of the polymers are tough & resistant to heat.
- b. Structure of the polymer: Cross linked & branched polymers are stronger than linear polymers

**2. Crystallinity:** The properties of a polymer such as density, modulus, resistance to heat, hardness etc are dependent on degree of crystallinity. If a polymer have high degree of crystallinity have more MP, more tensile strength and resistance to heat.

- a. Structure of polymers; Linear polymers without bulky groups & hydrogen bonding are more crystalline than branched & polymers have bulky groups.

Ex: HDPE High density polyethylene has high degree crystallinity than polyvinylacetate.

- b. **Configuration of the polymer:** Isotactic & syndiotactic Polymers are more crystalline than atactic polymers. Ex; Isotactic polyvinyl chloride is more crystalline than Atactic polyvinyl Chloride (random arrangements of groups)



A *trans* isomer (Gutta percha) is more crystalline than *cis* isomer (polyisoprene).

It also depends on polar groups & hydrogen bonding. Polymers having polar groups & hydrogen bonding have high degree of crystallinity.

- 3. Elasticity:** The elasticity is due to uncoiling & recoiling of the molecular chain on application of force. It should not break on prolonged stretching. The elasticity of a polymer can be improved.
  - a. By introducing cross linkages at suitable positions.
  - b. Avoiding side group such as aromatic and cyclic structures.
  - c. By introducing more non polar groups on the chain so that the chain does not separate on stretching.
  - d. By introducing internal plasticizers during polymerization.

**4. Chemical. Resistance:** Polymer should have more resistivity to chemical attack and should not become soft, swelling, or losing its strength. The chemical resistivity of a polymer depends on mainly.



- a. Presence of polar & non polar groups in the polymer chain: Presence of polar groups such as –OH, -COOH, are less resistance to chemical attack. But non-polar groups such as –CH<sub>3</sub>, -C<sub>6</sub>H<sub>5</sub>, NHCO, etc., are not usually attacked by chemicals. Ex: PVC, ABS, PS, etc., have high resistance towards chemicals.
- b. Degree of crystallinity & Molecular mass: Chemical resistance increases with increase in degree of crystallinity because crystalline regions make the penetration of chemicals or solvent more difficult. Higher the degree of crystallinity higher is the chemical resistance.

**Resins** are linear, low molecular weight polymeric materials. These further undergo polymerization and cross linking during curing to form hard and rigid three dimensional networks. These resins are used as coatings, adhesives and moulding powders.

Ex: Epoxy resin, Phenol-formaldehyde resin, Urea - formaldehyde resin, Polyester resin

**Plastics** are linear, high molecular weight polymeric materials, which can be moulded by the application of heat and pressure. During the process of moulding, these become hard but retain plasticity.

Ex: Polyethylene, Polystyrene, Poly vinyl chloride etc.

## **Synthesis Properties and applications of some important polymers**

### **Elastomers**

These are the high polymers which undergoes very long elongation when they are subjected to an external force and readily regains their original shape when stress is released ( when external force is removed).

Ex: Rubber.

### **Advantages of Synthetic Rubbers over natural Rubber**

1. These are more resistance to heat & cold ( nitrile rubber)
2. These are not easily attacked by sunlight & air ( neoprene and nitrilerubber)
3. These have high abrasion and high tensile strength.
4. Rubber property is retained at high temperatures (Ex: silicone rubbers- 900 - 3160 c)
5. Do not age easily (Ex; Polyurethane rubber)

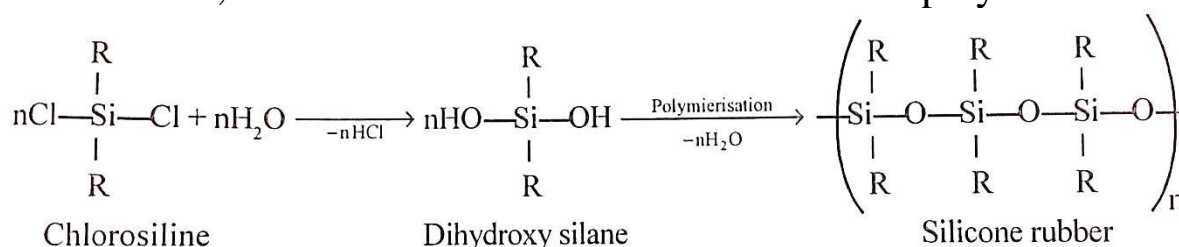
6. Do not swell and can hold organic solvent better than natural rubber(Ex; polysulphide rubber)
7. Hold more air and water at high pressures (Ex; butyl rubber)

### Vulcanization

Vulcanization is a chemical process for converting rubber or related polymers into more durable materials via the addition of sulfur or other equivalent "curatives". These additives modify the polymer by forming crosslinks (bridges) between individual polymer Chains, The vulcanized material is less sticky and has superior mechanical properties

### Silicone rubber:

**Synthesis:**Di Chlorosilane is treated with water, which produces a hydroxyl intermediate, which condenses to form silicon rubber polymer.

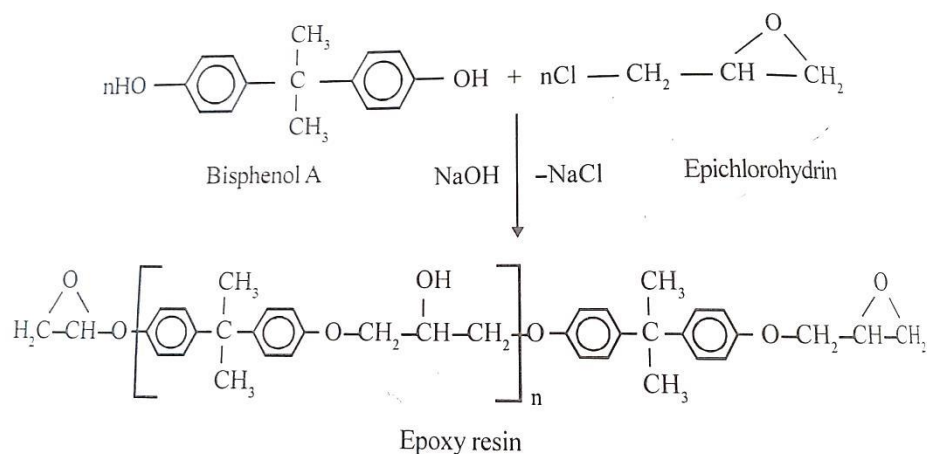


Properties	Applications
Silicone rubber is generally non-reactive, stable and resistant to extreme environments and temperatures from -55°C to +300°C.	Used in spark plug caps, radiator and automotive heating hoses.
Ability to repel water and form water tight seals.	Roller gaskets, window and door seals.
Good electrical insulator.	For medical devices such as tubing for dialysis, artificial respirators.
Good flexibility.	For making cooking and food storage products.

### Adhesives

Adhesives are the polymeric nonmetallic compounds which can hold firmly two materials together by surface attachment.

Ex: **Synthesis of Epoxy resinAraldite:** Bisphenol A is treated with Epichlorohydrin in presence of base to form epoxy resin.



Properties	Applications
Durable & has high impact resistance	It can be used to bind cardboard, boats, glass for laminating purposes.
Excellent chemical resistance.	Used in shrinkage proof garments.
Has good heat resistance	Used in industrial flooring, patching etc

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